

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Ionizing radiation can cause damage to living tissue. Scientists generally agree on the effects of high levels of exposure. But there is disagreement about the effects of low levels of exposure.

2.20 Introduction

Because ionizing radiation is high energy radiation which can knock electrons out of atoms and molecules, it can damage human tissue. The effects of ionizing radiation on the body depend on many things. First and most important, how much radiation energy was absorbed by the body? Second, what type of radiation was it? Third, what kind of cells—and how many of them—were exposed?

It was once thought that there might be a radiation exposure so low that there would be no risk associated with it. The risk of injury does decrease with decreasing exposure. But, while there may be very little likelihood of injury from exposures to low levels of radiation, some degree of risk is assumed when people are exposed to even very small amounts of radiation.

The damage done by radiation results from the way it affects *molecules* essential to the normal function of body cells. Four things may happen when radiation strikes a cell: 1) It may pass through the cell without doing any damage. 2) It may damage the cell, but the cell repairs the damage. 3) It may damage the cell so that the cell not only fails to repair itself but reproduces itself in damaged form over a period of years. 4) It may kill the cell. The death of a single cell may not be harmful, but serious problems occur if so many cells are killed in a particular organ that the organ no longer can function properly. Over time, incompletely or incorrectly repaired cells may produce delayed health effects such as cancer or genetic *mutations* or birth defects in babies exposed prior to birth.*

*Source: Primer on Radiation, FDA Consumer (HEW Publication No.) (FDA) 79-8099.

***What factors
determine the effects
of radiation on the
body?***

***Is there a threshold
for risk?***

***What can happen
when radiation
strikes a cell?***

What is the effect of exposure time?

Longer exposures to radiation increase the chance that damage will occur. However, if enough time passes between exposures, a higher total exposure may be tolerated than if the total exposure is received all at once. This effect is similar to the body's response to solar radiation — too much sun can cause a severe sunburn, but short exposures and sun block can limit the sun's burning effect on the skin.

Longer exposures to ionizing radiation allow some of the damaged cells to be repaired by the body, helping to reduce the overall effect. A damaged area may also be healed by healthy cells from an area not exposed to radiation. Radiation damage to **large** numbers of cells may be partially repaired, but some damage is permanent.

Does the amount of tissue exposed matter?

What cells are more sensitive to radiation?

The more tissue exposed to radiation, the greater the chance of injury. Exposure of the whole body, for instance, presents more risk than exposure of an arm or leg or single organ to the same radiation. Also, organs differ in how sensitive they are to radiation, so the type of cells exposed makes a difference. Rapidly dividing cells are generally more sensitive.

Tissue Sensitivity

Some cells, tissues, and organs are significantly more sensitive to radiation than others. Generally, organs with rapidly dividing cell systems, such as the bone marrow, gonads, and intestines, are more sensitive than non-dividing systems like the kidneys, liver, and brain. Cells that perform specialized functions are less sensitive than those that do not.

How do the types of radiation differ in the way they deposit energy?

What are some properties of alpha radiation?

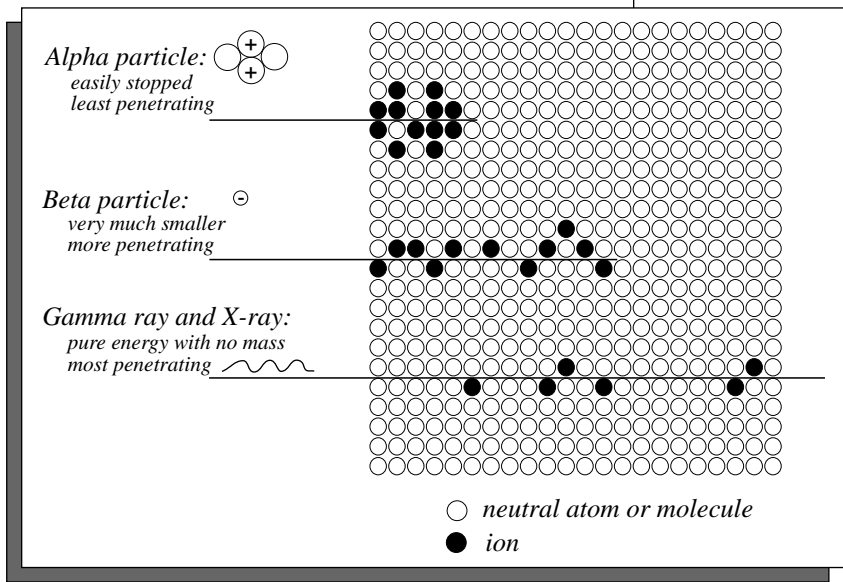
What are some properties of beta radiation?

The type of radiation is also important. Alpha, beta, and gamma radiations differ in both their abilities to penetrate tissue and in the likelihood that they will cause biological damage. Alpha particles are large and carry a double positive charge. They travel only a short distance in living tissue, but they deposit all their energy in that short path. This increases the likelihood that they will cause damage. Beta particles carry a single negative charge and are thousands of times smaller than alpha particles. They travel longer distances in living tissue than alpha particles, but deposit their energy over a longer path. For this reason, they are less likely to cause damage. Because alpha

and beta particles are not very penetrating, they mainly damage skin and surface organs. However, they can affect internal organs if substances giving off alpha and beta radiation are swallowed or inhaled.

Gamma rays and X-rays have similar properties, but gamma rays are generally more energetic. Their biological effects are similar. Their paths in living tissue are long. This means their energy is deposited over a longer path and is less likely to cause damage. But because they can penetrate the body more deeply, they can affect internal organs.

What are some properties of gamma and X-rays?



This drawing shows what the "paths" of different types of radiation might look like. Ions are formed when a particle, gamma ray, or X-ray penetrates tissue. Because alpha particles deposit all their energy along a short path, they are more likely to cause damage.

Source: Adapted from Radiation Activities for Youth Series, copyright The Pennsylvania State University, Nuclear Engineering Department, 1988. Permission for use granted.

2.21 Measuring Potential Health Effects

The basic unit for measuring radiation received is the *rad* (radiation absorbed dose). One rad equals the absorption of 100 *ergs** in every gram of tissue exposed to radiation.

To show biological risk, rads are converted to *rems*. The rem is adjusted to take into account the type of radiation absorbed and the differences in likelihood of damage from the different

How do we measure radiation exposure?

How do we estimate biological risk from exposure?

**erg - a small but measurable amount of energy (See glossary)*

types of radiation. But exposures are normally fractions of a rem, so the commonly used unit is the *millirem*.

$$1 \text{ millirem} = \frac{1}{1,000} \text{ of a rem}$$

2.22 Biological Effects

What are somatic effects?

There are two categories of effects from ionizing radiation: *somatic effects* and *genetic effects*. Somatic effects appear in the exposed person. They result from radiation damage to body cells that are **not** reproductive cells. They can occur soon after the exposure or they can take a number of years to become obvious. Somatic effects cannot be inherited.

What are genetic effects?

Genetic effects may appear in children conceived after a parent has been exposed to radiation if that parent's egg or sperm cells were affected. Genetic defects can be inherited.

What are the effects of acute exposures?

Large exposures in short periods of time (acute exposures) produce injuries within weeks or even hours. The severity

What is Radiation Sickness?

Acute exposure ranging from 100,000 to 400,000 millirem can result in any and/or all of the following effects.

Within hours or weeks: nausea, headache, loss of appetite, changes in blood cells.

Within succeeding weeks: loss of hair, hemorrhaging, diarrhea, effects on the central nervous system.

In most cases, prompt medical treatment gradually restores the patient's health.

Even larger exposures can destroy bone marrow cells. (This happened to some victims of the Chernobyl nuclear reactor accident in the Soviet Union in the 1980's.) Bone marrow transplants have been used to treat people exposed to large amounts of radiation, but results depend upon exposure and individual variations.

depends on the amount of radiation received. For example, 100,000 to 400,000 millirem, could cause *radiation sickness*. An exposure of 400,000 to 500,000 millirem within a short period of time, if left untreated, has a 50 percent chance of causing death in a population. An exposure of 500,000 millirem is nearly 1,500 times the 360 millirem exposure the average American receives from all sources in a year.

Exposure to low amounts of radiation (1,000 millirem or less) produces no observable effect. Larger exposures received over weeks or months may not produce visible symptoms. There is a slight

What are the effects of low exposures?

risk, however, that a delayed effect (such as cancer) could develop 10 to 40 years later. It's also possible (but even less likely) that damage to a reproductive cell could have occurred.

2.23 Ionizing Radiation and Cancer

Based on the cancer death rate of groups of people exposed to **large** amounts of ionizing radiation, we know that it can cause cancer. The most significant groups are 1) survivors of the atomic bombs dropped on Japan; 2) U.S. *radiologists* who used ionizing radiation from the 1920's through the 1940's to diagnose and treat medical problems; and 3) people given high X-ray exposures to treat a disease of the spine in the early days of radiation treatments.

No direct data exists to estimate the risk of death from cancer caused by low levels of ionizing radiation, such as we receive from our natural environment. Scientists agree on effects from high levels of exposure. But there is disagreement about effects of low levels of exposure. There is uncertainty about effects of low exposures because there is no direct data, and conclusions have to be made on the basis of information we have gathered about cancer deaths from high exposures.

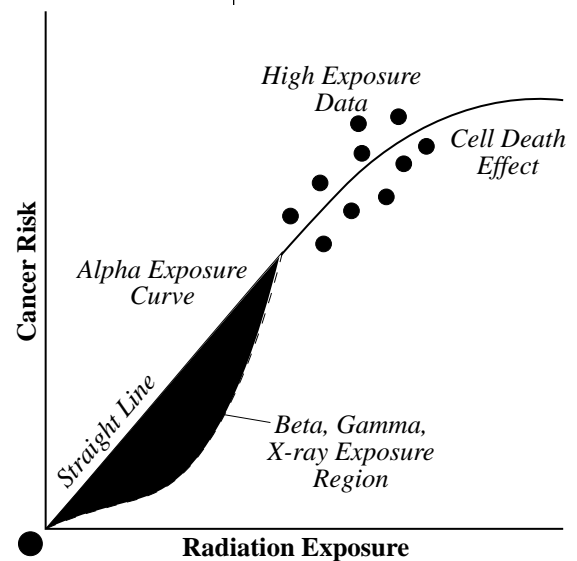
As you can see in the graph, risk of cancer death decreases as exposure to high levels of radiation decreases. The straight line drawn through the high exposure data down to zero is assumed to show fairly well the cancer death risks from low levels of exposure to alpha radiation. The effects of low exposures to beta, gamma, and X-ray radiation are more uncertain, as shown by the gray area of the graph.

Effects of low exposures to beta particles, gamma rays, or X-rays could be 2 to 10* times less than what would be predicted by the straight line.

* Source: *United Nations Scientific Committee on the Effects of Atomic Radiation: Sources, Effects and Risks of Ionizing Radiation*, 1988.

How do we know ionizing radiation can cause cancer?

Why are we concerned about low levels of ionizing radiation?



Cancer Risk versus Radiation Exposure: A straight line drawn to zero exposure through data of high exposures of alpha radiation. The effects of low exposures of beta, gamma, or X-ray radiation could be 2 to 10 times less than would be predicted by the straight line.

Many things cause cancer, including ultraviolet light, smoking tobacco, asbestos, and certain pesticides and many other chemicals. Statistics show that 17 percent of the people

Cancer Deaths Attributable to Various Sources^a

<u>Source</u>	<u>Cancer Deaths, Percent</u>
Diet	35 ^b
Tobacco	30 ^b
Infection	10 ^c
Sexual lifestyle	7 ^b
Occupation	4
Alcohol	3
Natural environment	3 ^d
Pollution	2
Medical care	1
Food additives	1
Industrial products	1
Unknown	— [*]

^a Adapted from R. Doll and R. Peto, *Journal of the National Cancer Institute*, vol. 66, 1981.

^b Ranges of possible percentages:
Diet, 10-70; Tobacco, 25-40; Sexual lifestyle, 1-13

^c Speculative; range not estimated

^d Includes background radiation

^{*} Sources of some common cancers unknown (e.g., prostate, bone marrow, lymph tissue); psychological contributions (such as stress) not identified

(170,000 out of 1 million) in the United States die from cancer from all causes. As you already know, average annual exposure for people living in the United States is about 300 millirem from **natural** sources. It is generally accepted among scientists that from one to three percent of all cancer deaths could be the result of this yearly exposure.

2.24 Effects on the Unborn

Many genetic and environmental factors affect development of babies before birth. For this reason, it is difficult to say with certainty how radiation exposure affects an unborn child. Therefore, information gathered from animal studies is generally used to estimate these effects.

Why is it hard to estimate how radiation affects an unborn child?

Animal studies have shown that exposure can result in a very wide range of results—from no observable damage to malformations of major organs of the body, slowed growth, damage to the central nervous system, and even death. Effects vary depending on the stage of development at the time of exposure and the level of exposure. Since experimental studies are not conducted on humans, the major sources of information about effects on humans are survivors of the atomic bombs in Japan and patients exposed during medical diagnosis or treatment. The most commonly reported abnormalities are defects to the central nervous system and slowed growth.

Rapidly dividing cells are especially sensitive to radiation. So, before birth and during infancy when children grow rapidly, medical exposures to radiation carry a risk. Scientists generally agree that exposure to ordinary diagnostic X-ray is **not** likely to be harmful. Nevertheless, it is important to balance benefits of exposure to radiation against risks. It is wise for a woman of child-bearing age to determine whether or not she is pregnant before being exposed to radiation above background levels. This precaution can help avoid unnecessary risk.

2.25 Birth Defects: A Fact of Life

Approximately 10 percent of all children born (100 thousand out of a million) have some genetic defect. These defects range from those so mild they are never noticed to those that are severe and even fatal. Spontaneous defects occur when unknown factors cause cells to not work properly. Defects may also occur because cells are affected by something in the environment, including ionizing radiation.

Genetic effects are effects that are inherited by the offspring of an individual whose egg or sperm cells have been damaged. No hereditary defects caused by ionizing radiation have been observed in humans, even among Japanese survivors of the atomic bombs. However, there is enough data from laboratory studies (most often using mice) to predict such effects.

What data on humans is available?

How common are birth defects?

Have genetic defects from radiation been observed in humans?

2.26 DNA: Mighty Molecules

What is DNA?

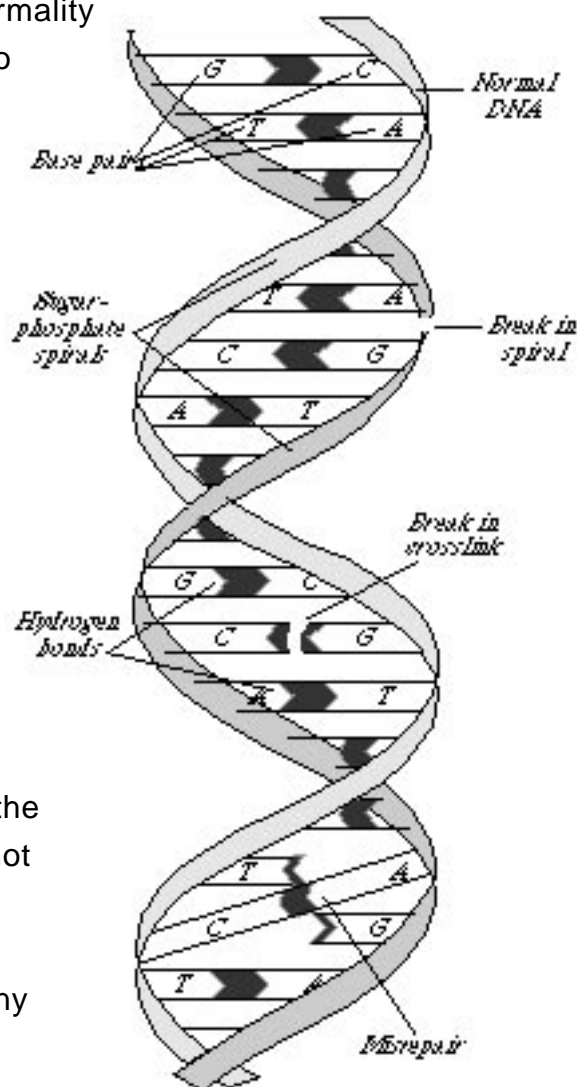
Why are they important?

What kinds of damage can happen to DNA?

Our bodies are made up entirely of cells. You were formed—and continue to grow—because cells continue to divide and reproduce themselves. Very large molecules in our cells determine what types of cells will form, making us what and who we are. These molecules are called *DNA*, which stands for *deoxyribonucleic acid*.

Take a close look at the drawing of a DNA molecule. Notice that the top section shows a normal, healthy arrangement. The second and third sections, on the other hand, show two different types of damage to DNA. The second section shows the most common type of injury, a break in the spiral. The third section contains a break in one of the crosslinks. The fourth section illustrates how the body might incorrectly repair a crosslink. An abnormality like this can be passed on to many cells.

Our bodies are composed of **billions** of cells. It's not surprising, then, to learn that damage to DNA occurs all the time. For the most part, our bodies simply go about their business of repairing damage. DNA repair does take a certain amount of time, however, and too much injury within a given time can overwhelm the ability of the body to repair the damage. If the damage is not repaired—or if it is repaired incorrectly—the results are passed along to a great many cells.



One of the many causes of damage to DNA is ionizing radiation. Low exposures usually do not affect the body's ability to repair damage. But high levels of exposure can damage such a large number of DNA molecules that repair (or proper repair) is less likely. This increases the possibility of harmful health effects.

There is some indication that radiation causes cancer by a DNA defect or incorrect repair. However, exactly how radiation or any other cancer-causing agents cause cancer is still not completely understood. It is also uncertain whether low exposures to ionizing radiation cause cancer. However, because we cannot prove that there is no effect, some small risk is assumed for any low level of exposure greater than zero.

Genetic disorders are also related to defects in DNA. But many things may cause genetic disorders, and many disorders caused by radiation can't be distinguished from those with other causes. Nevertheless, as with cancer, some small risk is assumed for any level of radiation exposure.

What is the possible effect of damage to DNA?